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ALTERNATIVE FIXED-RATIO FIXED-INTERVAL SCHEDULES OF REINFORCEMENT

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Five rats were trained under alternative fixed-ratio fixed-interval schedules, in which food reinforcement was provided for the completion of either a fixed-ratio or a fixed-interval requirement, whichever was met first. Overall response rate and running rate (the rate of responding after the postreinforcement pause) decreased for all subjects as the fixed-ratio value increased. As the proportion of reinforcements obtained from the fixed-ratio component increased and the alternative schedule approached a simple fixed ratio, overall response rate and running rate both increased; conversely, as the proportion of reinforcements obtained from the fixed-interval component increased and the alternative schedule approached a simple fixed interval, response rates decreased. Postreinforcement pause length increased linearly as the average time between reinforcements increased, regardless of the schedule parameters. A break-run pattern of responding was predominant at low- and medium-valued fixed ratios. All subjects displayed at least occasional positively accelerated responding within interreinforcement intervals at higher fixed-ratio values.

Key words: alternative schedules, fixed ratio, fixed interval, response rate, running rate, postreinforcement pause, lever press, rats

Complex schedules of reinforcement comprise combinations of simple schedules; they most often combine ratio and interval components. In alternative and interlocking fixed-ratio fixed-interval (FR FI) schedules, reinforcement is achieved both by responding and by the passage of time. Hence, a tradeoff between reinforcement frequency and responses per reinforcement exists; as response rate increases, time between reinforcements decreases, but the number of responses between successive reinforcements increases. The relationship between reinforcement frequency and responses per reinforcement on these schedules depends on their component FR and FI values: as the FR requirement approaches infinity, the schedules approach simple FI; as the FI requirement approaches infinity, the schedules approach simple FR.

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Studies of interlocking schedules show that responding varies in an orderly manner with the values of the FR and FI components. Berryman and Nevin (1962) and Powers (1968) found that response rate increased as the FI requirement increased, and response rate decreased as the FR requirement increased. The present study provides information about comparable alternative schedules.

The present study also provides information regarding determinants of postreinforcement pause length. A pause is characteristic of both FR and FI schedules: pause length increases monotonically as the value of either FR (Felton & Lyon, 1966; Powell, 1968) or FI (Harzem, 1969; Innis & Staddon, 1971; Lowe & Harzem, 1977; Schneider, 1969; Shull, 1970, 1971; Skinner, 1938; Wilson, 1954) is increased.

Nevin (1973) plotted pause length recorded by Berryman and Nevin (1962) in their study of FR, FI, and interlocking FR FI schedules as a function of the average time between successive reinforcements. Pause length was a linear function of the average interreinforcement interval. Nevin concluded that pause length on "fixed, cyclic, schedules of reinforcement . . . is a constant fraction of the time between reinforcements, regardless of whether reinforcement is programmed on a ratio schedule, an interval schedule, or an intermediate

interlocking schedule" (1973, p. 209). The present study permits a further test of Nevin's conclusion by providing pause data from another fixed, cyclic schedule of reinforcement in which time between reinforcements depends on a subject's performance.

METHOD

Subjects

Five naive male albino rats, three months old at the start of the experiment, were maintained at 80% of their free-feeding weights. The rats were obtained from Midcontinent Research Animals, Shawnee, Kansas.

Apparatus

A Gerbrands Model C Student Research Operant Conditioning Unit enclosed in a Coleman ice chest was used. The chamber measured 23.3 cm long, 20.3 cm wide, and 19.3 cm high. A lever, 4.0 cm wide and 1.4 cm thick, protruded 1.5 cm from the center of the front chamber wall, 8.0 cm above the floor. To the left of the lever was a receptacle into which 45-mg Noyes Precision Food Pellets, used as reinforcers, were dispensed. The receptacle was recessed, extending 5.0 cm behind the chamber wall. An aperture 4.5 cm wide and 4.5 cm high permitted access to the receptacle. A 6-W houselight was situated 10.5 cm above the floor on the front wall, directly above the aperture to the pellet receptacle. A relay provided auditory feedback whenever the lever was depressed. A fan, mounted on the Coleman chest, ventilated the experimental space.

Contingencies were arranged and data were collected by standard electromechanical equipment located in the same room as the experimental chamber. Equipment noise was masked by the fan, white noise inside the ice chest, and the noise of equipment controlling other experiments.

Pretraining

Two sessions were devoted to magazine training. In the next two sessions, each lever press was followed by food and animals remained in the chamber for 2 hr or until 60 reinforcements were obtained, whichever occurred first. All subjects learned to lever press during these two sessions. In the fifth session, an alternative FR 3 FI 2-min schedule was in effect. The FR requirement was raised gradually to 30 over the course of 3 to 9 sessions, depending on the stability of each subject's performance. The houselight illuminated the chamber throughout all sessions except during operation of the pellet dispenser (approximately 50 msec).

Experimental Procedures

The rats responded on alternative FR FI schedules with FR values ranging from 15 to 210 and FI values of 2 min and 4 min. Reinforcement was arranged independently by a ratio counter and a timer; reinforcement was produced by the completion of the ratio requirement or by the first response following the passage of a fixed interval of time, whichever occurred first. Both the ratio counter and the interval timer reset with each reinforcement. As in pretraining, the houselight flashed off during operation of the pellet dispenser.

Table 1 lists the schedule requirements and the number of sessions at each requirement for each rat. Condition changes were made only when no consistent trend in response rate was evident for at least five consecutive sessions.

Sessions were terminated with the first reinforcement after 60 min and were conducted 6 or 7 days per week at approximately the same time each day.

RESULTS

The mean response rate during the last five sessions in each condition, along with the lowest and the highest daily response rates from those five sessions, are given for each rat in Table 1. With few exceptions, response rates in any of the last five sessions in a condition deviated by less than 10% from that 5-day mean response rate.

Figure 1 shows overall response rates, averaged over the last five sessions of each condition, as a function of the schedule requirements for each rat. Generally, response rate decreased as the FR value increased, whether the alternative interval component was FI 2-min or FI 4-min.

Table 1 shows the number of reinforcements derived from each component. At some FR values, which varied from subject to subject, all reinforcements were obtained from the FR component; at this point, whether the FI component was 2 min or 4 min, the schedule functioned as a simple FR. Similarly, a ratio

Table 1

Alternative schedule parameters, number of sessions in each condition, response rates during the final five sessions in each condition, and reinforcements from each component of the alternative schedules during the final five sessions in each condition.

	Schedule Values			*Response rates*			*Reinforcements*		
Subject	*FR*	*FI*	*Sessions*	*Low*	*Mean*	*High*	*From FR*	*From FI*	*Total*
Rat 66	30	2 min	48	4.0	5.1	6.1	6	143	149
	15	2 min	46	12.4	14.0	14.9	261	58	319
	30	2 min	100	5.5	6.6	7.5	35	117	152
	60	2 min	42	2.7	3.4	3.9	0	133	133
	60	4 min	19	1.5	1.8	2.1	0	62	62
	15	4 min	49	16.8	17.5	18.3	350	6	356
	30	4 min	31	17.0	18.2	19.2	175	16	191
Rat 67	30	2 min	34	58.3	62.3	66.2	622	0	622
	60	2 min	35	80.1	84.4	90.2	421	1	422
	120	2 min	67	24.9	25.5	26.6	20	136	156
	150	2 min	18	15.8	17.4	18.3	2	148	150
	180	2 min	33	15.6	17.4	18.6	0	149	149
	180	4 min	73	5.5	7.2	9.8	1	72	73
Rat 68	30	2 min	35	82.8	85.4	87.9	861	0	861
	60	2 min	20	87.0	89.1	92.0	450	1	451
	120	2 min	38	53.4	56.1	60.3	93	88	181
	150	2 min	45	43.6	45.5	47.8	40	123	163
	180	2 min	27	31.8	35.3	37.5	9	139	148
	210	2 min	59	21.8	22.9	24.9	0	150	150
	210	4 min	32	1.3	2.6	3.5	0	52	52
	30	4 min	33	84.6	89.7	94.7	895	0	895
	90	4 min	33	62.9	69.9	75.6	237	2	239
Rat 75	30	2 min	19	102.4	106.9	111.3	1072	0	1072
	60	2 min	16	113.8	116.4	118.8	586	0	586
	120	2 min	24	72.3	74.5	77.1	168	47	215
	150	2 min	91	13.1	13.7	14.6	0	147	147
	150	4 min	98	1.7	2.4	3.2	0	72	72
	30	4 min	86	75.0	80.6	84.7	799	0	799
Rat 76	30	2 min	53	90.1	92.9	96.4	935	1	936
	120	2 min	36	24.7	27.1	28.8	9	145	154
	150	2 min	50	14.2	15.7	17.2	0	153	153
	150	4 min	26	5.2	5.6	6.2	0	75	75
	30	4 min	25	63.8	66.7	70.4	681	0	681
	60	4 min	32	42.8	47.1	50.4	241	5	246
	60	2 min	23	50.8	54.0	57.9	260	24	284
	90	2 min	51	22.3	23.9	24.8	15	138	153

ultimately was reached that was never completed within the time specified by the FI component; at this point, the schedule functioned as a simple FI. At intermediate FR values, some reinforcements were obtained from each component, at which points the alternative schedules were intermediate between simple FR and FI schedules. In Figure 2, response rates are correlated with the proportion of reinforcements obtained from the FR component. Response rate increased as the proportion of reinforcements obtained from the FR component increased, at both FI 2-min and FI 4-min. That is, response rate increased as the alternative schedule approached simple FR and decreased as the schedule approached simple FI.

Figure 3 shows pause length in sec averaged over the last five sessions of each condition, as a function of the schedule requirements for each rat. Individual pauses were measured from reinforcement to the first response after reinforcement with the stipulation that responses within 1 sec of reinforcement did not terminate the pause. Length of the pause generally increased as the FR value increased for all subjects whether the alternative interval component was FI 2-min or FI 4-min.

Pause length is correlated with the average time between successive reinforcements in each

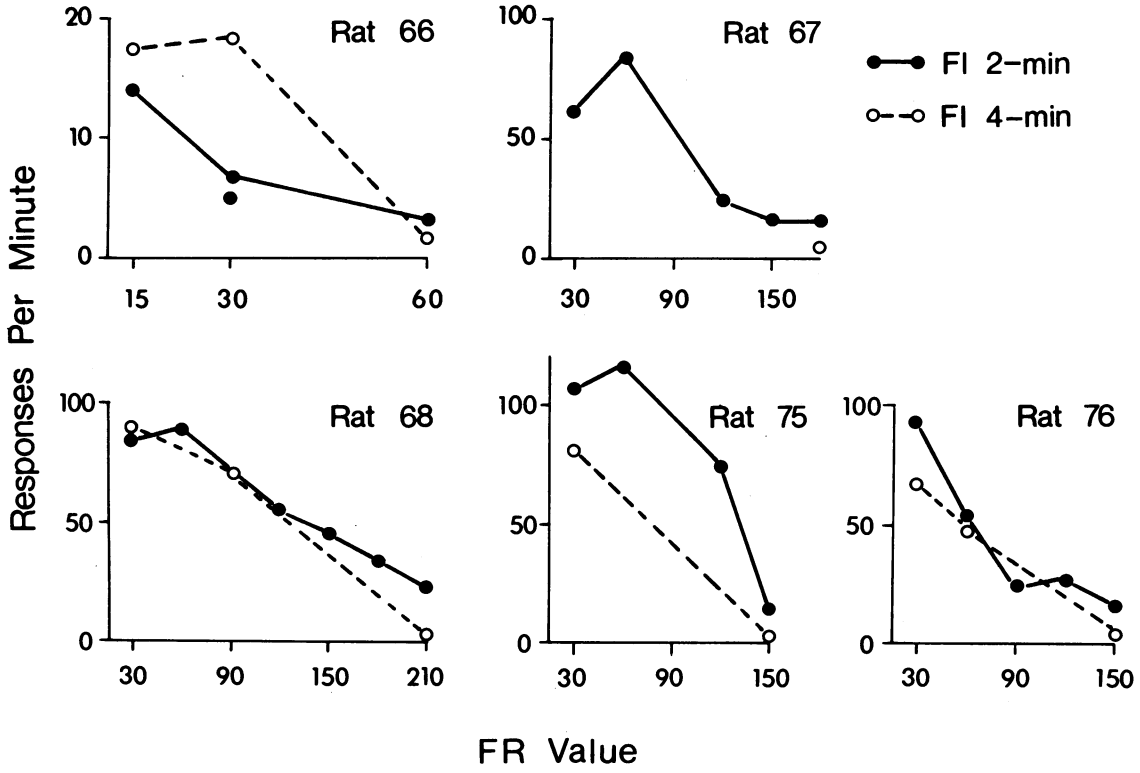

Fig. 1. Overall response rates as a function of the alternative schedule requirements. The unconnected data point for Rat 66 represents his first of two contacts with *alt* FR 30 FI 2-min. Note the different scales used for Rat 66.

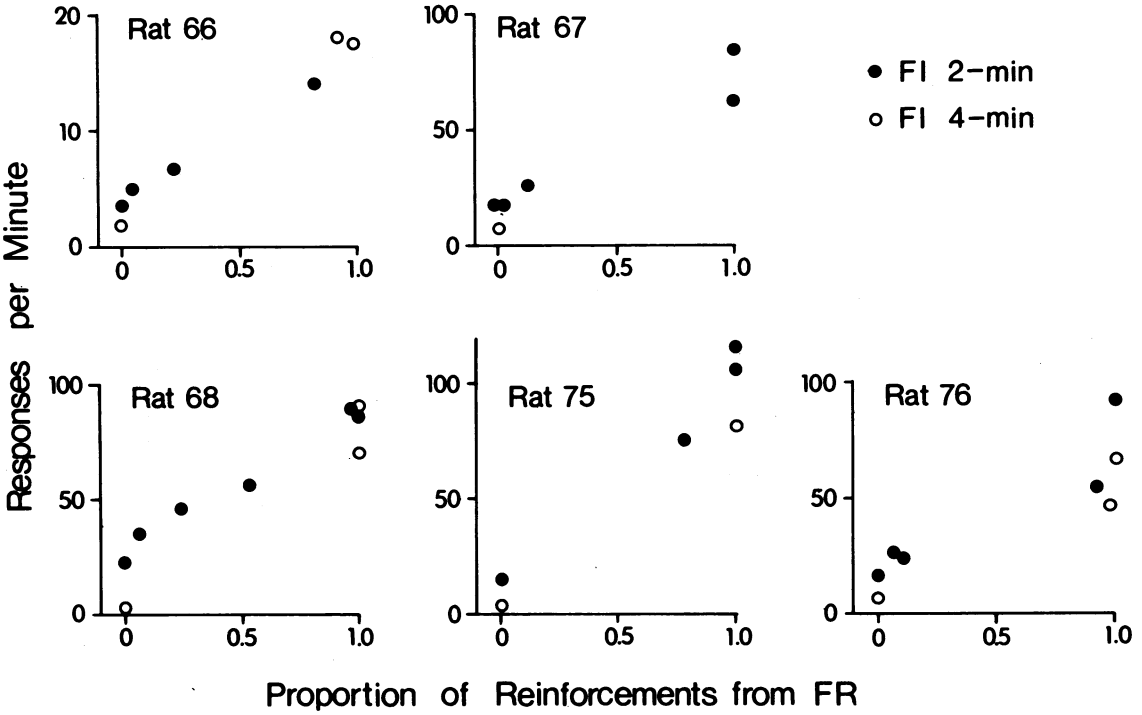

Fig. 2. Overall response rates as a function of the proportion of reinforcements obtained from the FR component. Note that the y-axis for Rat 66 is scaled differently from the other subjects.

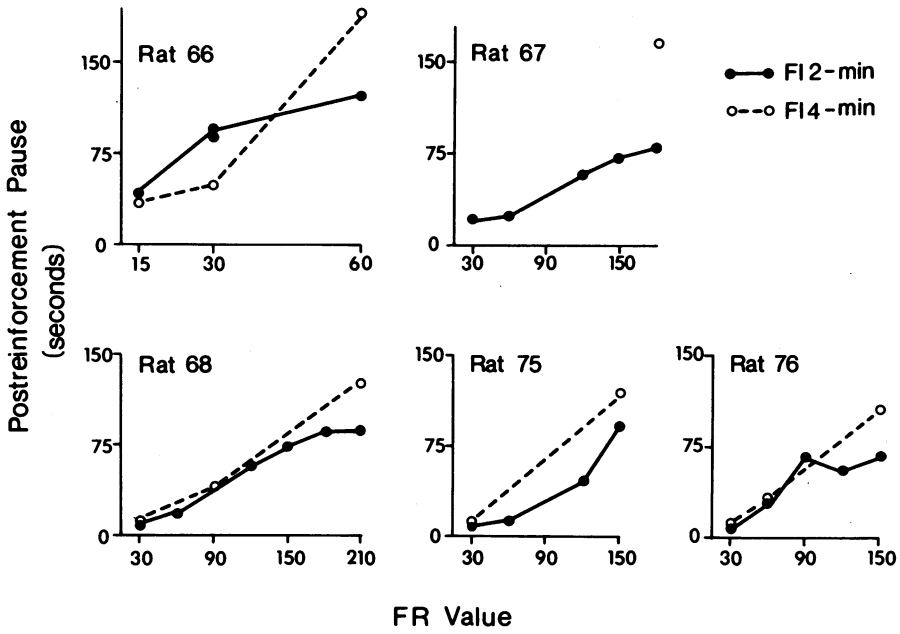

Fig. 3. Postreinforcement pause length as a function of the values of the alternative schedule requirements. The unconnected data point for Rat 66 represents his first of two contacts with *alt* FR 30 FI 2-min. Note the different scales used for Rat 66.

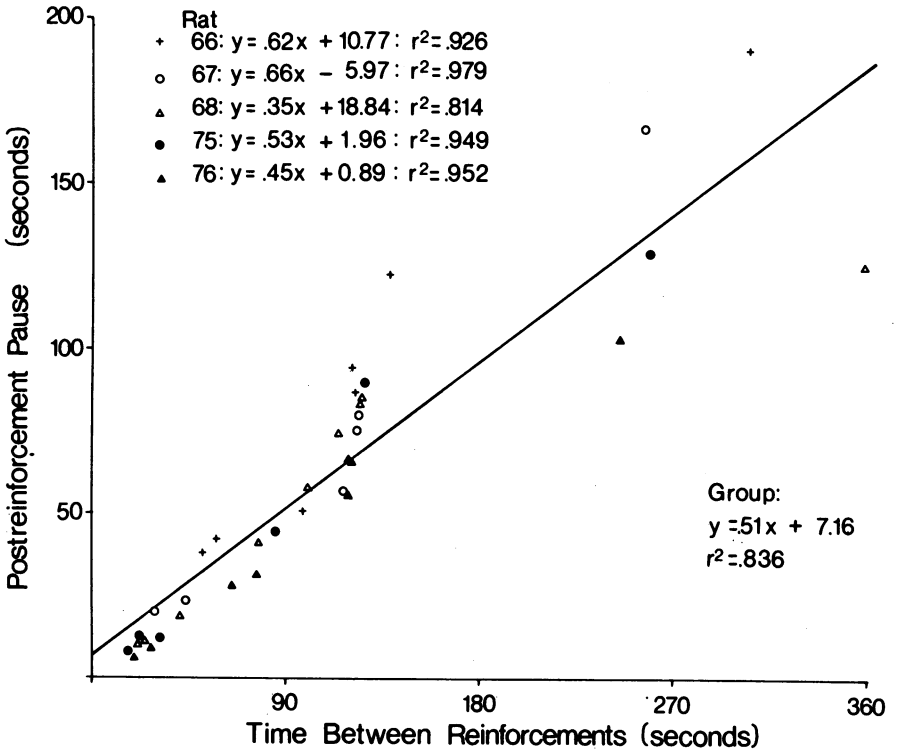

Fig. 4. Postreinforcement pause length as a function of the average time between reinforcements in each condition.

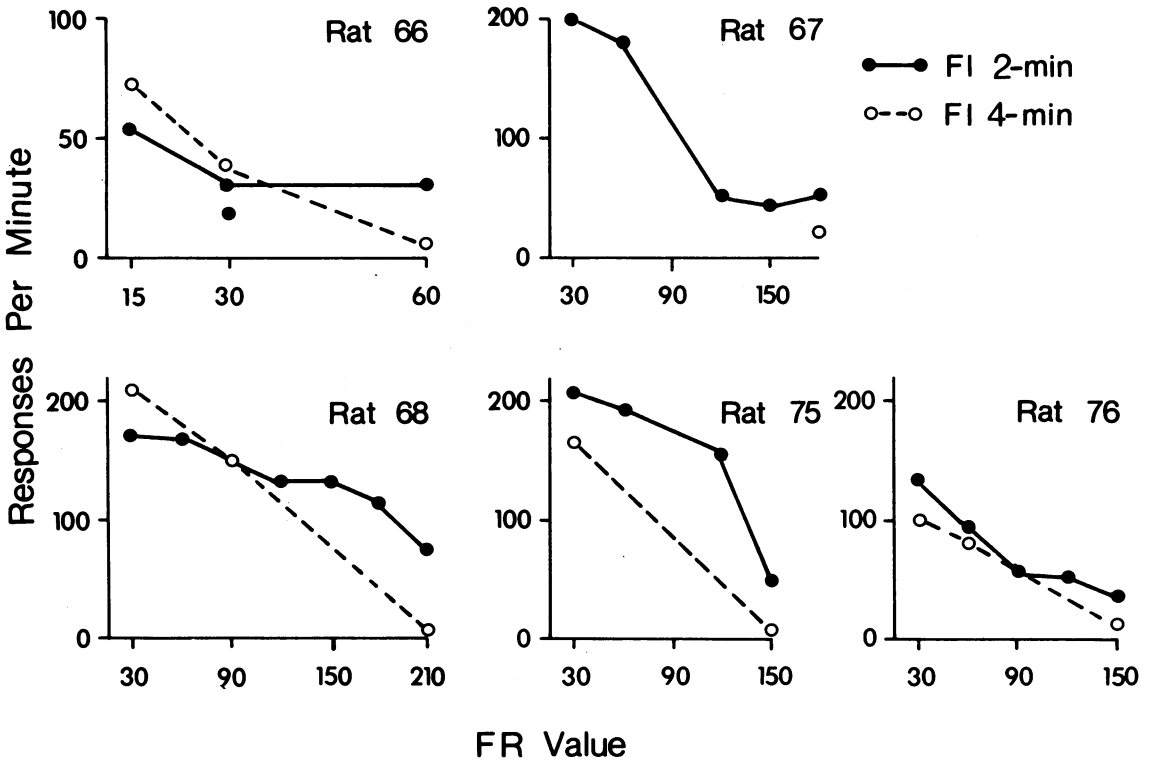

Fig. 5. Rates of responding after the postreinforcement pause (running rates) as a function of the alternative schedule requirements. The unconnected data point for Rat 66 represents his first of two contacts with *alt* FR 30 FI 2-min. Note the different scales used for Rat 66.

condition in Figure 4. The relation between pause length and interreinforcement time on these alternative schedules was similar to that on Berryman and Nevin's (1962) FR, FI, and interlocking schedules. The least-squares linear regression equation for Berryman and Nevin's group of 4 rats is:

$$y = .67x - 4.52; r^2 = .839,$$

where y is pause length in sec, x is the average time in sec between reinforcements, and r^2 is the coefficient of determination. The least-squares linear regression equation for the group in the present study is:

$$y = .51x + 7.16; r^2 = .836.$$

Figure 5 shows running rates, averaged over the last five sessions of each condition, as a function of the schedule requirements for each rat. Running rates were calculated by dividing total responses in a session by session time minus pause time. Running rate decreased as the FR value increased for all subjects, both with FI 2-min and FI 4-min. These data indicate that the changes in overall response rate (Figures 1 and 2) were not due strictly to changes in pause length. Rather, increases in the FR value were accompanied by both increases in pause length and decreases in running rates for all subjects, at both FI 2-min and FI 4-min.

Running rate, like overall response rate, also increased as the proportion of reinforcements obtained from the FR component increased for all subjects, at both FI values.

Patterns of Responding

Sample cumulative records in Figures 6 and 7 (Rat 68) and Figures 8 and 9 (Rat 76) illustrate changes in responding that corresponded with changes in the FR value of the alternative schedules. Each record represents a subject's stable performance on a schedule during one of the last five sessions in a condition.

At relatively low FR values, responding by all subjects resembled that characteristic of

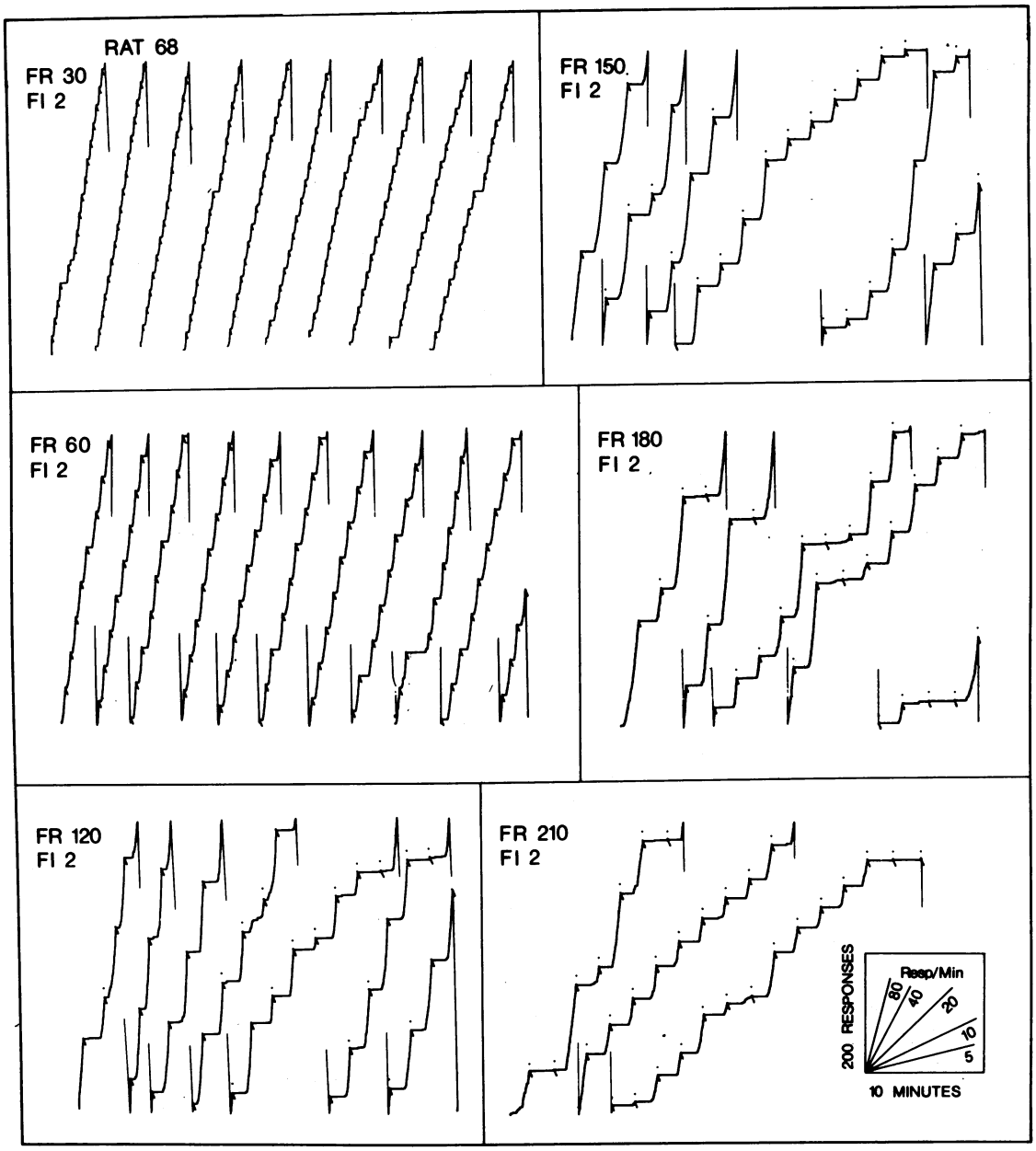

Fig. 6. Cumulative records for complete sessions of Rat 68 on *alt* FR × FI 2-min. Reinforcements obtained via the FI component are indicated by a dot above a reinforcement pip.

simple FR performance: periods of no responding immediately following reinforcement alternated with very high rates of responding until the next reinforcement. For most subjects, this break-run pattern of responding persisted through intermediate FR values even though reinforcement was delivered occasionally from the FI component before a ratio was completed or, less frequently, for the first response following an unusually long pause. Positively accelerated responding, often characteristic of simple FI performance, was evident in some interreinforcement intervals at the highest FR values. Both patterns—break-run and positive acceleration—often occurred in the same session.

Rat 68 displayed the most consistent break-run pattern of responding throughout the

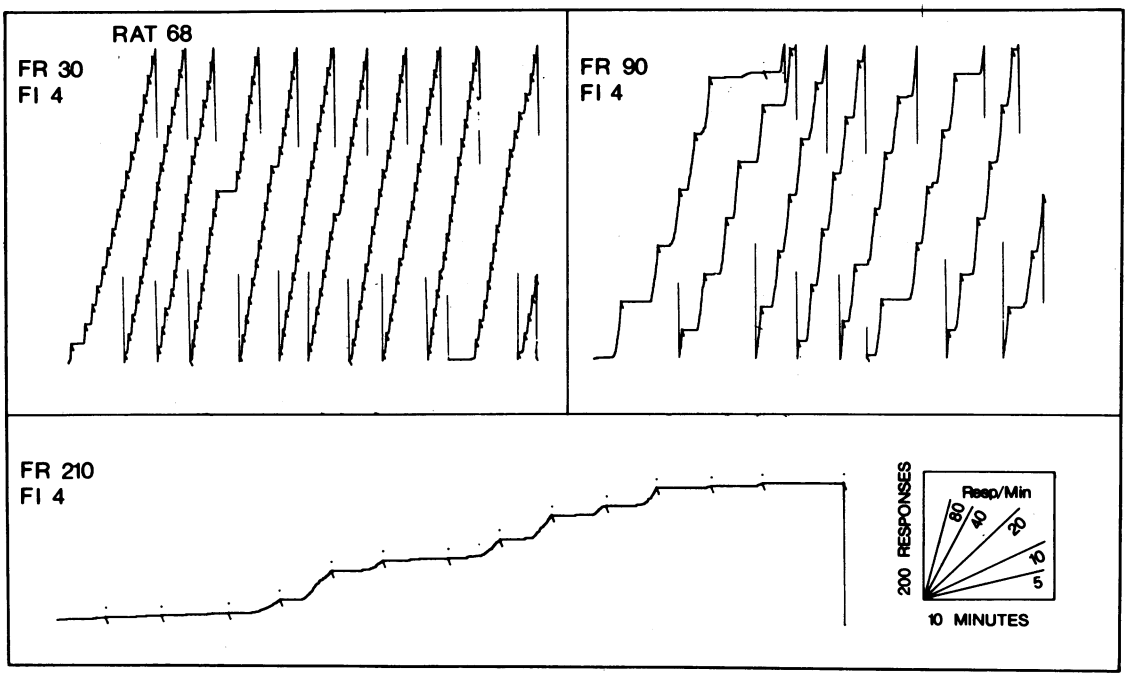

Fig. 7. Cumulative records for complete sessions of Rat 68 on *alt* FR × FI 4-min. Reinforcements obtained via the FI component are indicated by a dot above a reinforced pip.

range of FR values studied, with only occasional periods of positive acceleration at high FR values. Rat 76, on the other hand, displayed the most consistent positive acceleration of response rate at high and intermediate FR values. Thus, cumulative records of responding by these subjects represent the range of control over the patterns of responding exerted by the alternative schedules.

DISCUSSION

The present study revealed orderly relations between FR value on alternative FR FI schedules of reinforcement and three measures of responding: as the FR value increased, overall response rate and running rate decreased and pause length increased. In addition, responding within interreinforcement intervals tended to shift from a break-run pattern to a pattern of positive acceleration as the FR value increased.

These measures of responding also were correlated with changes in the proportion of reinforcements obtained from each component of the alternative schedules: as the proportion of reinforcements obtained from the FI component increased and the alternative schedule approached simple FI, overall response rate and running rate decreased, pause length increased, and responding tended to shift from a break-run pattern to a pattern of positive acceleration. Conversely, as the proportion of reinforcements obtained from the FR component increased and the alternative schedule approached simple FR, overall response rate and running rate increased, pause length decreased, and responding shifted from positive acceleration to a break-run pattern. These results are consistent with those of Berryman and Nevin (1962) and Powers (1968), who found that response rate increased on interlocking schedules as they approached simple FR, and decreased as the schedules approached simple FI.

Pause length increased monotonically as the average time between reinforcements increased on the alternative schedules, regardless of their component FR and FI values, and this relation was described well by a linear regression equation. This finding supports Nevin's (1973) conclusion that pause length increases linearly with the time between reinforcements on fixed, cyclic schedules of reinforcement.

Zeiler (1977) noted that most studies of the effect of FR value on response rate have confounded the direct effects of responses per reinforcement with the indirect effects of re-

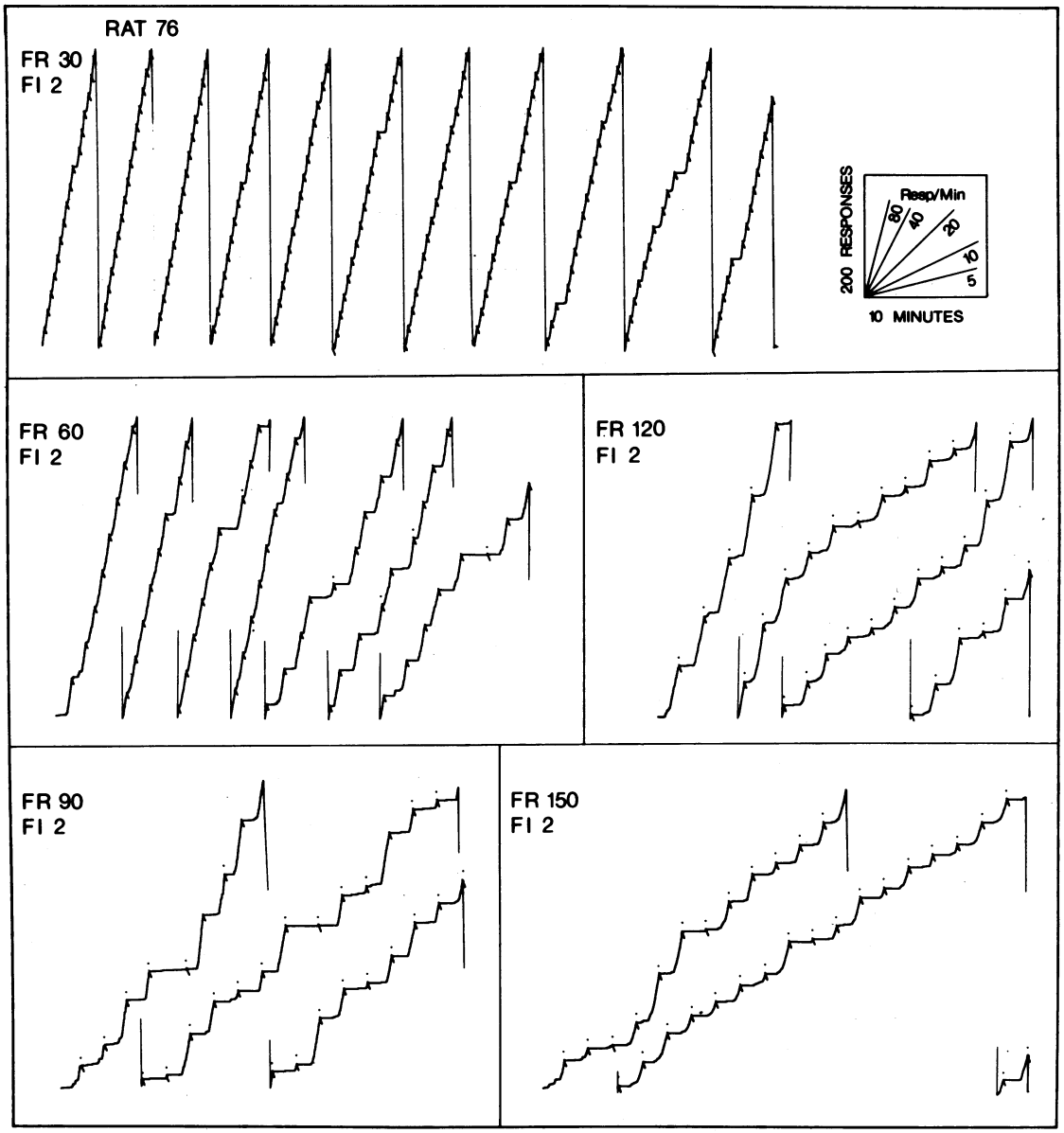

Fig. 8. Cumulative records for complete sessions of Rat 76 on *alt* FR × FI 2-min. Reinforcements obtained via the FI component are indicated by a dot above a reinforcement pip.

inforcement frequency. That is, the time between successive reinforcements usually increases as FR value increases. In the present experiment, FR value was varied across conditions but a maximum interreinforcement interval (and hence a minimum reinforcement frequency) was specified by the alternative schedule's FI component. Reinforcement frequency varied considerably as a function of the FR value when most reinforcements were obtained from the FR component, and a general decrease in overall response rate corresponded to decreases in reinforcement frequency. However, as the proportion of reinforcements obtained from the FI component increased, reinforcement frequency often remained relatively unchanged over several experimental conditions. Despite the stability of reinforcement frequency, response rate continued to vary as a function of the FR value.

The changes in responding appear to be the result of changes in the relative impact

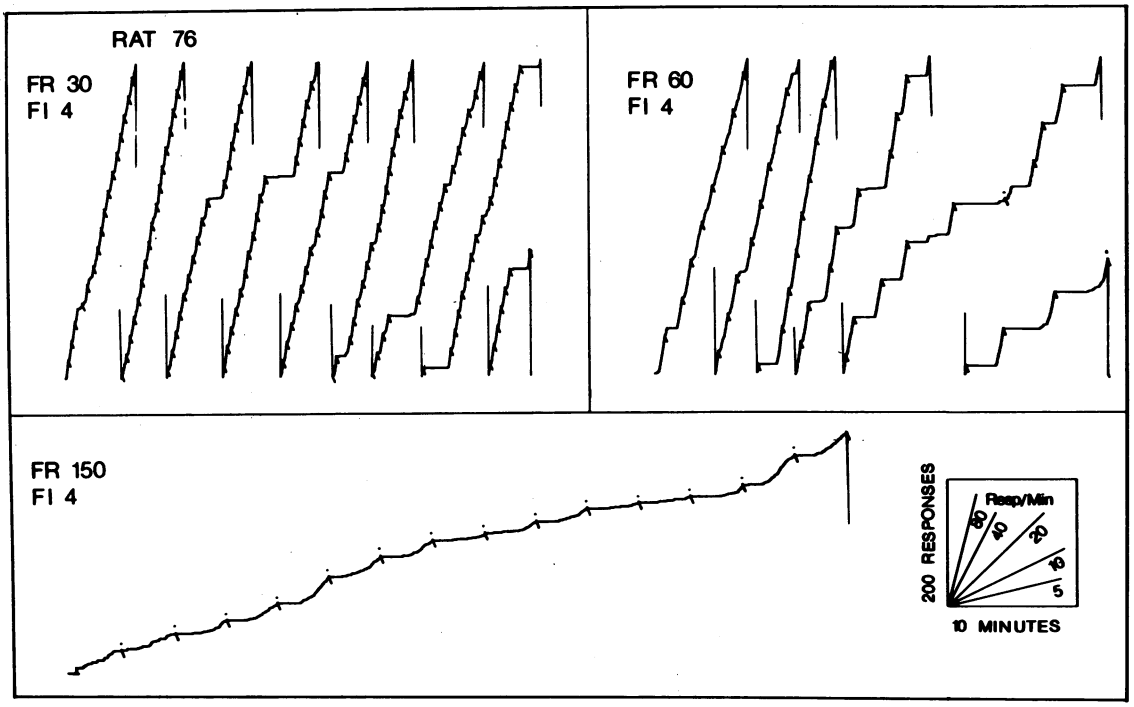

Fig. 9. Cumulative records for complete sessions of Rat 76 on *alt* FR × FI 4-min. Reinforcements obtained via the FI component are indicated by a dot above a reinforcement pip.

of the response and time requirements imposed by the alternative schedules. As the response requirement increased, responding was contacted less frequently by the FR component and more frequently by the FI component, and responding became more FI-like. Similarly, as the response requirement decreased, responding was contacted more frequently by the FR component and less frequently by the FI component, and responding became more FR-like.

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